

# An Examination of the Spectra of the "Kick-Out" Pulses for a Proposed Sampling Oscilloscope Calibration Method

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**Abstract**—The spectra of the "kick-out" pulses used in a proposed sampler calibration method [1]–[3] were examined. The proposed calibration method requires that the amplitude of these pulses be linear with an adjustment parameter called the offset voltage. The kick-out pulses were observed to have a nonlinear dependence on offset voltage, and this may affect the application of the proposed calibration method.

**Index Terms**—Frequency spectra, kick-out pulse, nose-to-nose calibration method, offset voltage, pulse metrology, sampler calibration.

## I. INTRODUCTION

CALIBRATION of the impulse response or transfer function of high-speed/high-bandwidth samplers can be performed with either time- or frequency-domain techniques. Time-domain techniques are typically used because of the difficulty in obtaining phase information from typical frequency-domain methods. However, time-domain techniques require having an accurately known pulse as a reference, and obtaining this reference pulse is difficult. Some time-domain methods that are being explored for sampler calibration use a photoconductively-generated electrical pulse for the reference pulse, and this pulse is calibrated by measuring it with other photoconductors or electrooptically [4], [5]. Another proposed sampler calibration method is the "nose-to-nose" (ntn) method, which was introduced ten years ago, and is based on the argument that the generated pulse is equal to the sampler impulse response [1]–[3].

## II. EXPERIMENT

In the ntn technique, a series of kick-out pulses are measured using a set of three samplers. Each sampler in turn acts as a source of the kick-out pulse. Kick-out pulses are produced when the sampling structure (a diode bridge) is strobed while under bias (the offset voltage). The kick-out pulses propagate to the input terminal of the sampler. The samplers are physically and electrically situated such that the distance between their input connectors is minimized, resulting in an "ntn" appearance. We used two 50 GHz (–3 dB attenuation bandwidth) digital sampling oscilloscopes; both samplers were triggered using a short transition duration step (17 ps transition duration, 0.25 V amplitude before a wide-band splitter) with a 2-kHz repetition rate. A series of waveforms were acquired by setting the "offset voltage" parameter of

the vertical axis of the oscilloscope to values between –500 mV and +500 mV (parameter limits) in 25 mV increments. The offset voltage of the sampler receiving the kick-out pulse was set to 0.0 V. The acquired kick-out waveforms have 1.5 ns epochs, contain 1024 elements, and are each the result of 256 waveforms internally averaged by the oscilloscope.

The acquired kick-out waveform  $W_V(t)$  also contains a signal contribution from the sampling-diode strobe pulse, that is

$$W_V(t) = s_V(t) + k_V(t) \quad (1)$$

where  $s_V(t)$  is the coupled strobe pulse and  $k_V(t)$  is the kick-out pulse, both at the offset voltage  $V$ . Consequently, to obtain an estimate of  $k_V(t)$ ,  $s_V(t)$  must be removed [2]. To remove the strobe pulse contribution, two acquired waveforms are used, one that is obtained with a negative offset voltage and another that is obtained with a positive offset voltage of equal magnitude  $W_{-V}(t)$  and  $W_{+V}(t)$ . The  $W_{-V}(t)$  and  $W_{+V}(t)$  are the result of the convolution of the kick-out pulse, the impulse response of the sampler-to-sampler adapter, and the impulse response of the measuring sampler. The kick-out pulse is dependent on the response of the sampler diode to the strobe pulse, and this response may be affected by the offset voltage. Furthermore, the coupling of the strobe pulse through the diode may be affected by the offset voltage. To obtain a waveform  $D_V(t)$ , where the strobe pulse contribution has been minimized (but not eliminated, as will be shown later) and the amplitude scaled appropriately, the difference of  $W_{-V}(t)$  and  $W_{+V}(t)$  is computed and the result divided by two [2]

$$D_V(t) = \frac{W_{+V}(t) - W_{-V}(t)}{2} \quad (2)$$

$D_V(t)$  will equal  $k_V(t)$  only if  $k_{-V}(t) = -k_{+V}(t)$  and  $s_{-V}(t) = s_{+V}(t)$ . If the offset voltage drifts or varies, then to ensure the sampler can be calibrated accurately, requires that the offset voltage be measured and that  $k_{\alpha V}(t) = \alpha k_{+V}(t)$ , where  $\alpha$  is a real-valued constant. Furthermore, if the latter requirement is not met, then the impulse response estimate derived from the ntn method is suspect.

## III. RESULTS AND DISCUSSION

Fourier transforms were taken of the  $D_V(t)$  to examine the effect of offset voltage. Fig. 1 shows the spectra of  $D_V(t)$  for various offset voltages and normalized to the magnitude of their corresponding dc components. Fig. 1 shows that the normalized magnitude spectra of the  $D_V(t)$  are dependent on the offset voltage; they do not overlap exactly for any offset voltages, and

Manuscript received September 24, 1999; revised May 25, 2001.  
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Publisher Item Identifier S 0018-9456(01)08758-7.

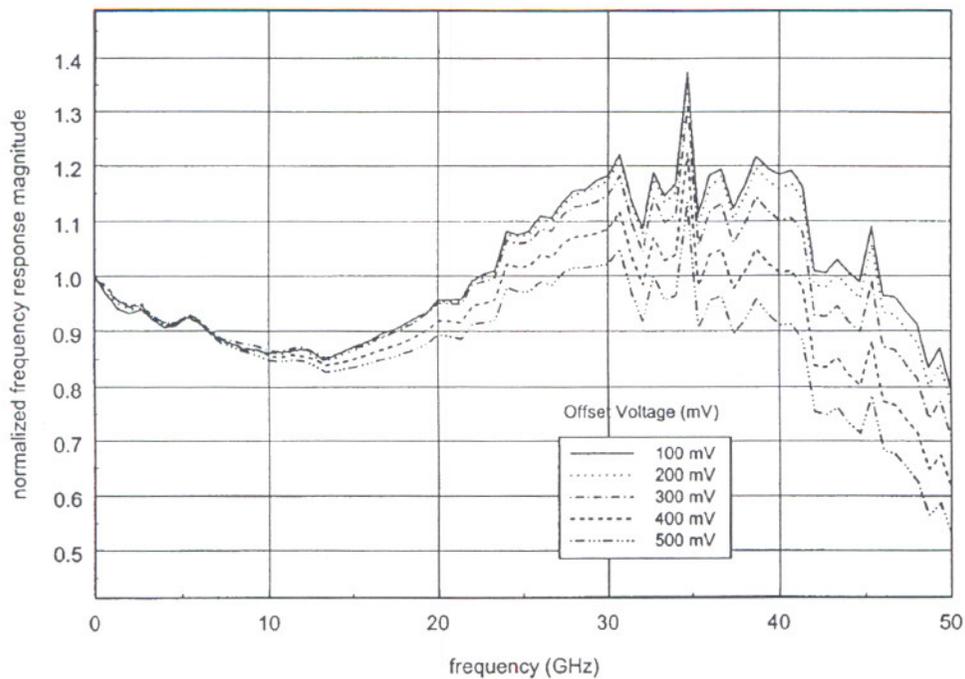


Fig. 1. Magnitude spectra of acquired waveforms  $D_V(t)$  for offset voltages of 100 mV, 200 mV, 300 mV, 400 mV, and 500 mV normalized to the magnitude of their corresponding dc components.

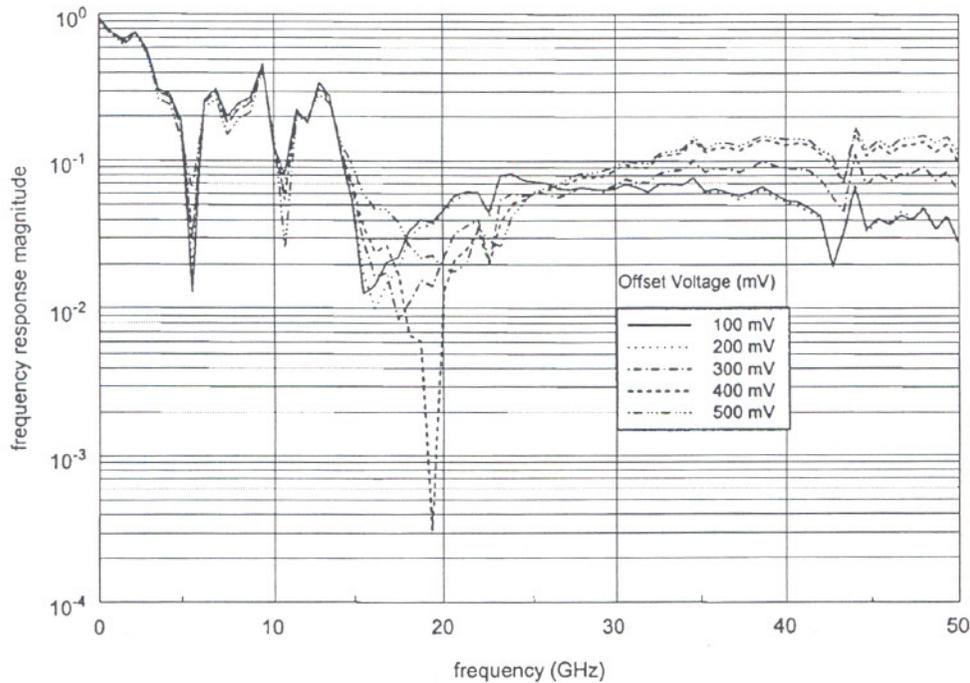


Fig. 2. Magnitude of the spectrum of the coupled strobe pulse.

this limits the applicability of the ntn technique. That is, the variation in the difference waveform with offset voltage weakens the argument that the kick-out pulse equals (or approximates) the sampler impulse response. These offset-voltage dependencies may be acceptable for routine sampler calibration but may not be acceptable for more demanding calibrations. An accurate assessment of the ntn technique for sampler calibration requires a complete measurement process uncertainty analysis

which is presently in progress. To examine whether the strobe pulse contributes to the observed offset-voltage dependencies, strobe pulse waveforms were determined using

$$S_V(t) = \frac{W_{+V}(t) + W_{-V}(t)}{2} \quad (3)$$

The magnitude spectra results for different  $S_V(t)$  are shown in Fig. 2. This figure shows that the strobe pulse coupling is de-

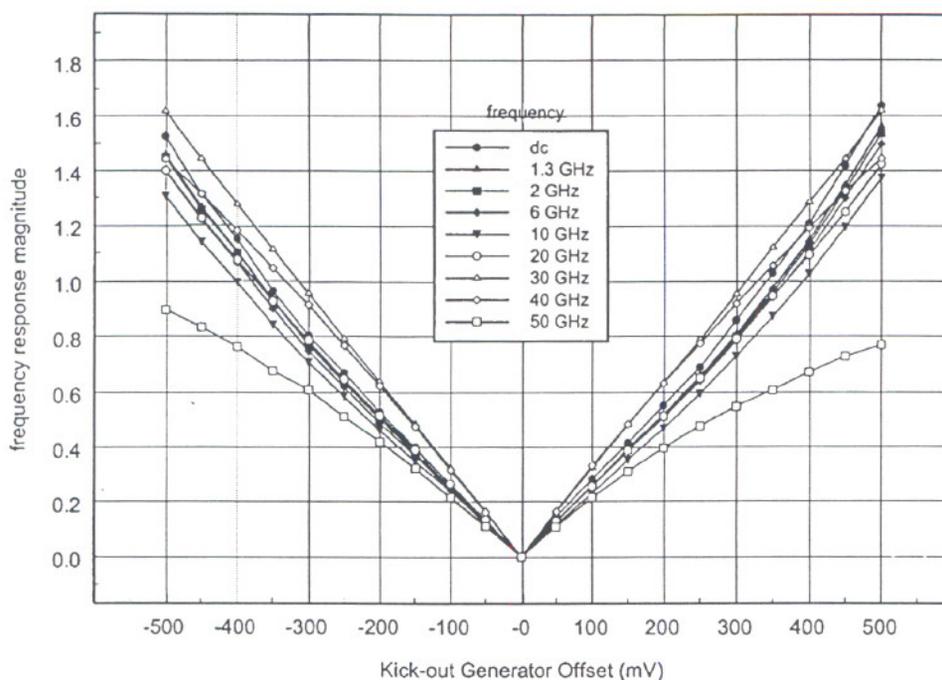


Fig. 3. Magnitude of specific components of the spectra of kick-out pulses. The kick-out spectra were obtained by subtracting the spectrum of the coupled strobe pulse (obtained setting the offset voltage to 0 V) from the spectra of the acquired kick-out waveforms  $W_V(t)$ .

pendent on offset voltage. For frequencies greater than about 15 GHz, the difference in the spectra of the  $S_V(t)$  is large. There also appears to be an anomaly near the offset voltage setting of 400 mV. To obtain a clearer picture of the kick-out pulse offset-voltage dependence, the magnitudes of specific components of the spectra of the kick-out pulses, where the spectrum of the 0-V-offset-voltage kick-out pulse has been subtracted, were examined (see Fig. 3). Ideally, the points representing the negative offset voltages should be a mirror image of the points representing the positive offset voltages. This is not the case, and the asymmetry is worse at higher offset voltages than at lower offset voltages. However, whether offset-voltage dependent strobe coupling and/or offset-voltage dependent kick-out pulse generation are the cause for the nonideal curves, shown in Fig. 3, has not been determined.

The spectra of the acquired waveforms show a dependence on offset voltage (see Fig. 3) and this limits the upper range of useful (for sampler calibration purposes) offset voltages to the range of  $\leq \pm 200$  mV. Furthermore, we have observed that the peak-to-peak amplitude of the kick-out pulses is not linear with offset voltage for offset voltage magnitudes  $\leq 100$  mV [6], which puts a lower limit on the offset voltage. The amplitude of  $W_{\pm 50 \text{ mV}}(t)$  (about 30 mV) is much greater than the noise level (less than 100  $\mu\text{V}$  rms), so the 100 mV lower limit is not a noise-based limit.

#### ACKNOWLEDGMENT

The authors would like to thank T. M. Souders and P. D. Hale of the National Institute of Standards and Technology (NIST) for technical comments, and B. A. Bell of NIST for administrative support.

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